VENUS AERIAL PLATFORMS AND ENGINEERING AND SCIENTIFIC MODELING NEEDS

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Introduction: NASA's Planetary Science Division is performing an assessment of the state of technology in aerial platforms for exploration of Venus. A key factor in the design of aerial platforms is knowledge of the Venus environment. Modeling the Venus environment, which is the subject of this workshop, is needed for the design of robust aerial platforms that can carry out their missions successfully. The purpose of this paper is to enumerate the kinds of models that are important for both engineering and scientific aspects of the design of an aerial platform mission. The first meeting of the NASA Aerial Platforms study team took place from May 30 to June 2, 2017 and defined the science that can be performed by aerial platforms. A second study meeting is planned for late November 2017. This paper focuses on the current status.

Aerial Platforms at Venus: The first and only aerial platform missions to have been carried out at Venus were the VeGA balloons deployed by the Soviet Union in 1985 [1]. Each of them floated in the the superrotating atmosphere for approximately two days at a near constant altitude of 55 km altitude and were successfully tracked from Earth. VeGA was an important proof of principle and has led to concepts for more ambitious missions to follow

Constant altitude balloon: One direction that has been pursued involves scaling up the VeGa concept, enabling larger payloads and missions of longer duration but still at a constant altitude. The technology needed here is still the superpressure type of balloon used for VeGa but with stronger material and greater protection against the sulfuric acid environment. These vehicles can also be used to deploy/relay data from descent probes as in the Venus Climate Mission endorsed by the Planetary Science Decadal Survey in 2011 [2].

Altitude controlled balloon: A more ambitious capability is a vehicle which can change altitude in a controlled fashion enabling atmospheric sampling over a broad range of altitudes. Concepts for implementing this over an altitude range from 70 to 30 km have been explored [3].

Hybrid airship concepts: Concepts have also been devised with some degree of horizontal control. The Venus Atmospheric Maneuverable Platform (VAMP) would use a combination of flotation and lift to rise to 65 km on the dayside of Venus but sink to 50km on the night side when no solar power is available [4].

Solar powered airplane: Solar power near the cloud tops on Venus is adequate for powered flight. Heavier-than-Atmosphere (HTA) vehicles can remain in continuous sunlight by flying in the opposite direction to the superrotating flow [5]. However, cloud opacity and temperature will limit how deeply a solar airplane can penetrate into the cloud layers.

Deep atmosphere platforms: Concepts for buoyant vehicles that would operate near the surface of Venus have also been explored. These include concepts for lifting samples up to the more clement parts of the atmosphere for analysis since lifetimes of vehicles at the surface are limited to a few hours. A similar vehicle can also serve as the first stage in a Venus Surface Sample Return system. After arriving in low density regions of the atmosphere, the sample would be launched into orbit [6]. The Venus Mobile Explorer studied by the Planetary Science Decadal Survey [7] uses similar technology.

Environmental Modeling Needs: Knowledge of the Venus environment captured in models is vital for the design of atmospheric platforms and the missions they will implement.

Atmospheric circulation models: For balloon missions, it is necessary to know where the platform will travel in order to assess the likely duration of the mission. Current expectations are that superpressure balloons deployed at 55 km will drift towards the pole, but the rate at which this occurs is uncertain. For platforms with altitude control, it will be important to know if there is any variation in this meridional component of velocity; if it were to reverse, it might enable some degree of control of latitude. For hybrid airpships, the meridional component will determine how much control authority the vehicle will need to avoid drifting to pole.

Solar and thermal radiation models: Knowledge of the variation of solar radiation with depth in the cloud layer is needed for the design of many types of buoyant vehicle where heating of the envelope by the sun impacts performance. The solar flux is also a factor in the design of any long duration aerial platform mission dependent on solar power. Hybrid and HTA vehicles are most dependent on it because clearly their need for power for propulsion will limit how deep into the cloud deck the vehicles can descend. Altitude controlled balloon missions will be much less sensitive because they do not require power for propulsion. However, it will be important to know how deep in the atmosphere it will be practical to operate a solar power system. Performance is impacted by 1) the fall in the intensity of solar flux deeper in the clouds, 2) the selective loss of short wavelength radiation, and 3) the increase in temperature which selectively degrades the performance of photovoltaic converters of longer wave radiation. Models [8] for balloon design [2] should now be updated based on the Venus Express and Akatsuki data.

Cloud characteristics: The nature of the aerosols in the cloud layer and their size distribution will be important to aerial platform design. Balloon missions planned to date are very conservatively designed to tolerate immersion in sulfuric acid. However, if models indicate that sulfuric acid exists only as a very finely dispersed mist, this requirement might be relaxed. There may be other implications for balloon emissivity and thermal control, the surfaces of optical instrument, and for the entry ports of gas analyzers.

Physical properties and chemistry of the deep atmosphere: As explained in a companion paper by Josette Bellan, the behavior of mixtures of gases under high pressures and temperatures can introduce some counter intuitive behavior which may explain anomalous near surface lapse rates [9].

Scientific Modeling Needs: In addition to the need for models that can ensure that the aerial vehicle can survive, generate power, and access the parts of the atmosphere needed to execute its mission, models will also be needed to carry out scientific experiments. There will be many different types of models needed for this purpose but we include here a discussion of some that have been the subject of recent work by the senior author and his collaborators.

Infrasound generation and propagation: Seismic disturbances on Venus couple very efficiently into the atmosphere because of the density of the Venus atmosphere. Models have been developed to characterize the propagation into the atmosphere, which indicate that Rayleigh waveforms are accurately replicated as an acoustic signal according to work by Garcia [10]. However, models focusing on the epicentral wave that have been developed for the Earth still need to be adapted to Venus.

Infrasound background generation: To confirm the feasibility of detecting quake-related infrasound signatures, it is important to understand other sources of infrasound on Venus. Building on general circulation models, efforts are underway to understand the size of signals generated in the boundary layer [11]. If Venus has very levels of seismic activity, they may prove to be a source of excitation that can be used for probing the internal structure of the planet.

Engineering Modeling Needs: Models are also required to describe how engineering systems for aerial platforms interact with the environment. Some examples of these are described below:

Entry models: Modeling of concepts with rigid entry systems is well developed for Venus, although in need of refinement. Modeling for concepts where the vehicles enter the atmosphere in an inflated state are required.

Balloon and airship thermal models: Solar heating of the envelopes of balloons and airships elevates the temperature of the enclosed gas, increasing its pressure and exerting stress on the envelope. Improved models integrating the environmental effects are needed to characterize these effects.

Solar power generation models; Solar power is the most practical source of power. Models are needed to optimize the design of multijunction cells to account for the changing intensity, spectral content and temperature with depth in the atmosphere.

Navigation models: Localization of the vehicles is important to the science they can accomplish. Terrain relative navigation (TRN) requires viewing the surface at high resolution and is only possible within 10 km of the surface, and even there is degraded. Models characterizing surface visibility building on the pioneering work of Moroz [12] will be required.

Summary: The development of high fidelity models is vital for the further exploration of Venus and particularly for the operation and scientific utilization of aerial platforms. Environmental models are needed to characterize the environment in which the vehicles operate so they can be designed to effectively carry out their mission. Engineering models are needed to characterize the response of the vehicles to their environment so they survive entry, diurnal changes and acquire sufficient power for operation. Finally, purely scientific models are needed so that diagnostic signatures of the phenomena being investigated can be understood.

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